

jc6662 U.S. PTO  
03/07/00

Patent  
Attorney's Docket No. 004501-349

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

UTILITY PATENT  
APPLICATION TRANSMITTAL LETTER

jc542 U.S. PTO  
09/521107  
03/07/00

Box PATENT APPLICATION  
Assistant Commissioner for Patents  
Washington, D.C. 20231

Sir:

Enclosed for filing is the utility patent application of Silke Draber for METHOD FOR ASSESSING THE RELIABILITY OF TECHNICAL SYSTEMS.

Also enclosed are:

- ☒ 2 sheet(s) of drawing(s);
- ☒ a claim for foreign priority under 35 U.S.C. §§ 119 and/or 365 is ☒ hereby made to Appln. No. 199 10 098.5 filed in Germany on March 8, 1999; ☒ in the declaration;
- ☐ a certified copy of the priority document;
- ☐ a General Authorization for Petitions for Extensions of Time and Payment of Fees;
- ☐ \_\_\_\_\_ statement(s) claiming small entity status;
- ☐ an Assignment document;
- ☐ an Information Disclosure Statement; and
- ☒ Other: Preliminary Amendment.
- ☒ An ☐ executed ☒ unexecuted declaration of the inventor(s) ☒ also is enclosed ☐ will follow.
- ☐ Please amend the specification by inserting before the first line the sentence --This application claims priority under 35 U.S.C. §§119 and/or 365 to    filed in    on   ; the entire content of which is hereby incorporated by reference.--
- ☐ A bibliographic data entry sheet is enclosed.



21839

☒ The filing fee has been calculated as follows ☒ and in accordance with the enclosed preliminary amendment:

CLAIMS					
	NO. OF CLAIMS		EXTRA CLAIMS	RATE	FEE
Basic Application Fee					\$690.00 (101)
Total Claims	10	MINUS 20 =		x \$18.00 (103)	
Independent Claims	1	MINUS 3 =		x \$78.00 (102)	
If multiple dependent claims are presented, add \$260.00 (104)					
Total Application Fee					\$ 690.00
If verified Statement claiming small entity status is enclosed, subtract 50% of Total Application Fee					
Add Assignment Recording Fee of if Assignment document is enclosed					
<b>TOTAL APPLICATION FEE DUE</b>					<b>\$ 690.00</b>

☐ This application is being filed without a filing fee. Issuance of a Notice to File Missing Parts of Application is respectfully requested.

☒ A check in the amount of \$ 690.00 is enclosed for the fee due.

☐ Charge \$ \_\_\_\_\_ to Deposit Account No. 02-4800 for the fee due.

☒ The Commissioner is hereby authorized to charge any appropriate fees under 37 C.F.R. §§ 1.16, 1.17 and 1.21 that may be required by this paper, and to credit any overpayment, to Deposit Account No. 02-4800. This paper is submitted in duplicate.

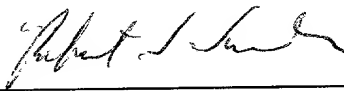
Please address all correspondence concerning the present application to:

Robert S. Swecker  
Burns, Doane, Swecker & Mathis, L.L.P.  
P.O. Box 1404  
Alexandria, Virginia 22313-1404.

Respectfully submitted,

BURNS, DOANE, SWECKER & MATHIS, L.L.P.

Date: March 7, 2000

By:   
Robert S. Swecker  
Registration No. 19,885

P.O. Box 1404  
Alexandria, Virginia 22313-1404  
(703) 836-6620

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In Re Application Of :  
SILKE DRABER : Group Art Unit: Unassigned  
Serial No. UNASSIGNED :  
Filed: March 7, 2000 :  
For: METHOD FOR ASSESSING THE :  
RELIABILITY OF TECHNICAL SYSTEMS :

**PRELIMINARY AMENDMENT**

Assistant Commissioner for Patents  
Washington, D.C. 20231

Sir:

Prior to examination, please amend the above-identified application as follows:

**IN THE CLAIMS:**

Claim 3, line 1, delete "one of claims 1-2", and insert --claim 1--.

Claim 6, line 1, delete "one of claims 1-5", and insert --claim 1--.

Claim 7, line 1, delete "one of claims 1-6", and insert --claim 1--.

Claim 8, line 1, delete "one of claims 1-7", and insert --claim 1--.

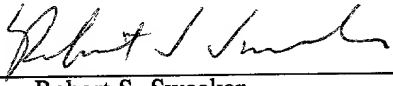
Claim 9, line 2, delete "one of claims 1-8", and insert --claim 1--.

**REMARKS**

The above amendments have been made to remove the multiple dependencies in the claims. Early and favorable action in connection with this application is respectfully requested.

Respectfully submitted,

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By   
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Date: March 7, 2000

## DESCRIPTION

## Method for assessing the reliability of technical systems

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The present invention relates to the field of reliability analysis of technical systems. It proceeds from a method for quantitative estimation of the reliability of a technical system according to the preamble of claim 1.

Such a method is known from the article by T. L. Regulinski and Y. P. Gupta, "Reliability Cost Estimation: Managerial Perspectives", IEEE Transactions on Reliability, Volume R-32, pages 276-281 (1983). A method is set forth there for estimating fault-induced costs in the life cycle of a system. Various failure probability distributions are postulated for the system components, depending on the fault mechanism, and their parameters are estimated statistically or by subjective expert opinion. An improved expert estimate is achieved by specifying an upper, mean and lower estimate for the failure rate and using them to determine a beta distribution of the failure rate. A unique cost estimate is calculated for the overall system from the beta distributions modeled in such a way. However, there is a problem that subjective estimates by one or a few experts lead to corrections between different failure rates, and the systematic falsification in an unknown way of the prediction of the system reliability.

Moreover, it is known that for types of fault with a constant fault rate the fault frequency, that is to say the randomness of the number of faults in a time interval, can be described by a Poisson distribution (see, for example, the textbook by A. Birolini, "Qualität und Zuverlässigkeit technischer Systeme"

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35 The method according to the invention largely cuts back the influence of systematic faults on the calculation of the system reliability by treating the expert estimates as being intercorrelated.

In a first exemplary embodiment, a mean value is respectively estimated in addition for the second fault rates and used to calculate a mean probability distribution. By adding the individual failure probabilities and by convoluting their distributions, it is possible to specify a graphical representation of the mean, maximum and minimum system reliability for a prediction period. The graphical representation permits a simple, intuitive risk assessment for the probability of a system failure or a cost overrun owing to maintenance, standstill and repair of a technical system.

In a further exemplary embodiment, a Poisson distribution is assumed for each first type of fault, an upwardly and downwardly displaced limiting Poisson distribution is determined for a required confidence level, and a widened Poisson distribution of the first type of fault is determined by weighted summing of the three Poisson distributions.

Further embodiments, advantages and applications of the invention follow from the dependent claims and from the description now following with the aid of the figures.

By way of example:

Figure 1 shows a representation according to the invention for the predicted probability  $W$  of a downtime of less than or equal to  $T_{\text{down}}$  (in hours) in the course of one year; and

Figure 2 shows a schematic representation of the calculation according to the invention of the system reliability in conjunction with an FMEA table.

Identical parts are provided with identical reference symbols in the figures.

The subject matter of the invention is a method for quantitative estimation of the reliability of a technical system. A system is understood to be in general terms an arbitrary machine or system, for example a turbine or a power plant, or a process for production or treatment. In this case, types of fault with associated fault rates are specified for the system components, and a probability distribution of a random variable characterizing the reliability is determined for the overall system and a prescribable time interval. First fault rates are determined by statistical random samples. Second fault rates are estimated by subjective expert opinion, an upper and a lower estimate being specified in each case. According to the invention, a first limiting probability distribution is calculated with the upper estimates, and a second limiting probability distribution is calculated with the lower estimates. Preferred exemplary embodiments are specified below.

For the second fault rates, it is additionally possible to estimate a mean value in each case and to calculate a mean probability distribution with the mean values. The values presumed to be the most probable are preferably estimated as mean values. The result can be summarized and illustrated in the form of a graphical representation in accordance with Figure 1. In the figure, a failure-induced downtime  $T_{\text{down}}$  during a year in hours is selected as random variable, and three probability distributions  $W(T_{\text{down}})$  1, 2, 3 are specified for the failure-induced downtime being less than or equal to  $T_{\text{down}}$ . In this case, 2 denotes a first or optimistic, and 3 a second or pessimistic, limiting probability distribution, and 1 denotes a mean probability distribution.

The aim for the first fault rates is to determine random sample mean values and assume distribution



functions, and to determine from the uncertainty of each random sample mean value a width or a widening of the associated distribution function. In particular, for each first type of fault, a Poisson distribution with a nominal expectation value equal to the random sample mean value is assumed, a minimum and a maximum expectation value are calculated from a required confidence level, and a widened Poisson distribution is calculated by weighted summing of the Poisson distributions with the nominal, minimum and maximum expectation values. According to the invention, a confidence level  $1-\alpha$  and weighting factors  $1-2\alpha$ ,  $\alpha$  and  $\alpha$  are selected for the Poisson distributions with the nominal, minimum and maximum expectation values.  $\alpha$  is typically selected in the range between 0.05 and 0.3, and in particular  $\alpha=0.1$ .

The model according to the invention of a widened probability distribution serves the purpose of taking appropriate account of the uncertainty in the knowledge of the expectation value of the fundamental probability distribution by widening the probability distribution. A computational example is specified below for a Poisson distribution. It may be assumed as known from operational experience or the like that a system component has a total of  $n_{\text{stat}}$  failures during one observation period  $t_{\text{stat}}$ . A nominal expectation value of the fundamental Poisson distribution is then given by  $\mu_{\text{nom}}=n_{\text{stat}}/t_{\text{stat}}*T$ , where  $T$ =time interval for the risk analysis or operating period of the overall system. Using a confidence level of, for example,  $1-\alpha=0.9$ , a lower and upper limit of a confidence interval is calculated for the expectation value using the following equations (after Koslow and Uschakow, Handbuch zur Berechnung der Zuverlässigkeit für Ingenieure, [Engineer's manual for calculating reliability], page 426 (1979)):  $\mu_{\text{low}}=n_{\text{low}}/t_{\text{stat}}*T$ ,  $\mu_{\text{up}}=n_{\text{up}}/t_{\text{stat}}*T$ , where  $n_{\text{low}}=0.5*\chi^2[\alpha/2](2n_{\text{stat}})$  and

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$n_{up}=0.5*\chi^2[1-\alpha/2](2n_{stat}+2)$ , where  $\chi^2[...](...)$  denote the (tabulated)  $\chi^2$  quantiles. In a departure from a customary  $\chi^2$  distribution, the factors 2 and 0.5 are determined by the Poisson distribution. The Poisson distributions with the expectation values  $\mu_{low}, \mu_{nom}$  and  $\mu_{up}$  are added to the weighting factors 0.1; 0.8 and 0.1, thus resulting in widening. According to the invention, the weighting factors for the two edge Poisson distributions are selected such that the sum of the components projecting upwards and downwards from the confidence interval (in each case, approximately half of the edge distributions) are exactly equal to the confidence level itself. The calculation of the Poisson widening is thereby largely self-consistent.

For a higher confidence level, the confidence interval is widened, the weighting factors for the edge distributions decrease, and the widening is diminished. If the time interval  $T$  for the risk analysis is substantially longer than the observation time  $t_{stat}$ , three separate maxima occur in the widened Poisson distribution. However, it is desirable to obtain a monomodal widened Poisson distribution. The edge weighting factors can be selected to be larger or smaller for this purpose, and/or the number of the Poisson distributions to be weighted can be enlarged.

Furthermore, in order to improve the prediction of the system reliability or the system risk analysis, account is taken of third types of fault whose fault rates are known a priori or with high statistical reliability, and for which an ideal Poisson distribution is assumed. The distribution functions of the first and third fault rates are convoluted, and the first and second limiting probability distributions 2, 3 and, if appropriate, a mean probability distribution 1 are calculated by adding the upper, lower and, if appropriate, mean estimates of the second fault rates. In addition, other

[illegible]

- The method is illustrated for the first types of fault in Figure 2. Widened Poisson distributions  $w_i$  are calculated 5 for each row of the FMEA or FMECA table 4 with a first type of fault and convoluted 6 to form an overall probability density distribution  $W$ , and an overall probability distribution  $W$  is determined 7 by integration. It is also possible to specify the probability distribution  $1-W$  such that the random variable, for example the failure-induced downtime in the prescribable time interval, is greater than  $T_{down}$ .

[illegible]

## LIST OF DESIGNATIONS

$T_{\text{down}}$	Failure-induced downtime
$W(T_{\text{down}})$	Probability distribution for a failure-induced downtime $\leq T_{\text{down}}$
1	Mean probability distribution
2	Optimistic probability distribution
3	Pessimistic probability distribution
4	FMEA table, FMECA table
5	Probability density distributions $w_i$ calculated by rows; widened Poisson distributions
6	Overall probability density distribution $w$ ; convolution of (widened) Poisson distributions
7	Overall probability distribution $W$

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## PATENT CLAIMS

1. A method for quantitative estimation of the reliability of a technical system, types of fault with associated fault rates being specified for the system components, and a probability distribution of a random variable characterizing the reliability being determined for the overall system and for a prescribable time interval, first fault rates being determined by statistical random samples, and second fault rates furthermore being estimated by subjective expert opinion and an upper and a lower estimate being specified in each case, characterized in that a first limiting probability distribution (2) is calculated with the upper estimates, and a second limiting probability distribution (3) is calculated with the lower estimates.
2. The method as claimed in claim 1, characterized in that
- a) a mean, in particular a most probable, value is additionally estimated in each case for the second fault rates, and
  - b) a mean probability distribution (1) is calculated with the mean values.
3. The method as claimed in one of claims 1-2, characterized in that
- a) random sample mean values are determined for first fault rates and distribution functions are assumed, and
  - b) a width or a widening of the associated distribution function is determined from the uncertainty of each random sample mean value.
4. The method as claimed in claim 3, characterized in that

- a) for each first type of fault, a Poisson distribution with a nominal expectation value equal to the random sample mean value is assumed,
- 5 b) a minimum and a maximum expectation value are calculated from a required confidence level, and
- 10 c) a widened Poisson distribution is calculated by weighted summing of the Poisson distributions with the nominal, minimum and maximum expectation values.
5. The method as claimed in claim 4, characterized in that
- 15 a) a confidence level  $1-\alpha$  and weighting factors  $1-2\alpha$ ,  $\alpha$  and  $\alpha$  are selected for the Poisson distributions with the nominal, minimum and maximum expectation values, and
- 20 b) in particular,  $\alpha=0.1$  is set.
6. The method as claimed in one of claims 1-5, characterized in that account is taken of third types of fault whose fault rates are known a priori or with high statistical reliability, and
- 25 for which a Poisson distribution is assumed.
7. The method as claimed in one of claims 1-6, characterized in that
- 30 a) distribution functions of the first and third fault rates are convoluted, and the first and second limiting probability distributions (2, 3) and, if appropriate, a mean probability distribution (1) are calculated by adding the upper, lower and, if appropriate, mean estimates of the second fault rates, and
- 35 b) in particular, other non-random variables relevant to the system reliability are

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determined for the time interval and added to the probability distributions.

- 5 8. The method as claimed in one of claims 1-7, characterized in that
- 10 a) the random variable characterizing the reliability is a susceptibility to faults, a downtime, costs of standstill, repair and maintenance, or variables derived therefrom, and
- 15 b) in particular, the fault rates are failure rates.
- 20 9. The application of the method in accordance with one of claims 1-8 in conjunction with FMEA tables, FMECA tables or tables (4) derived therefrom, characterized in that
- 25 a) first, second and third fault rates are distinguished in the tables (4),
- 30 b) random sample mean values and confidence intervals are specified for first fault rates,
- c) upper, lower and, if appropriate, mean estimates are specified for second fault rates, and
- 35 d) expectation values are specified for third fault rates.
10. The application of the method as claimed in claim 9, characterized in that
- a) Poisson distributions of the first and third types of fault are calculated and convoluted with one another, and
- b) the second fault rates are grouped into upper, lower and, if appropriate, mean fault rates and added separately in each case.



## ABSTRACT

The present invention relates to a method for quantitative estimation of the reliability of a technical system, which is useful, in particular, for complex systems with a multiplicity of components. First, second and third failure rates are distinguished for the system components. In accordance with the invention, an upper, lower and, if appropriate, mean value are in each case estimated for the largely unknown second failure rates by subjective expert opinion, and all upper, lower and, if appropriate, mean estimates are used separately to calculate an optimistic and pessimistic limiting probability distribution (2, 3) and, if appropriate, a mean probability distribution (1) of the system reliability. Systematic correlations between expert estimates are thereby taken into account. For the first failure rates, mean values obtained from operational experience are determined with a confidence interval, and widened Poisson distributions are calculated. Furthermore, it is possible to add to the overall probability of the system reliability the Poisson distributions of third types of fault whose failure rates are known a priori or with a high statistical reliability. The method is suitable, in particular, for use in connection with FMEA ("Failure/Fault Modes and Effects Analysis") tables (4) and FMECA ("Failure/Fault Modes, Effects and Criticality Analysis") tables (4).

(Figure 1)

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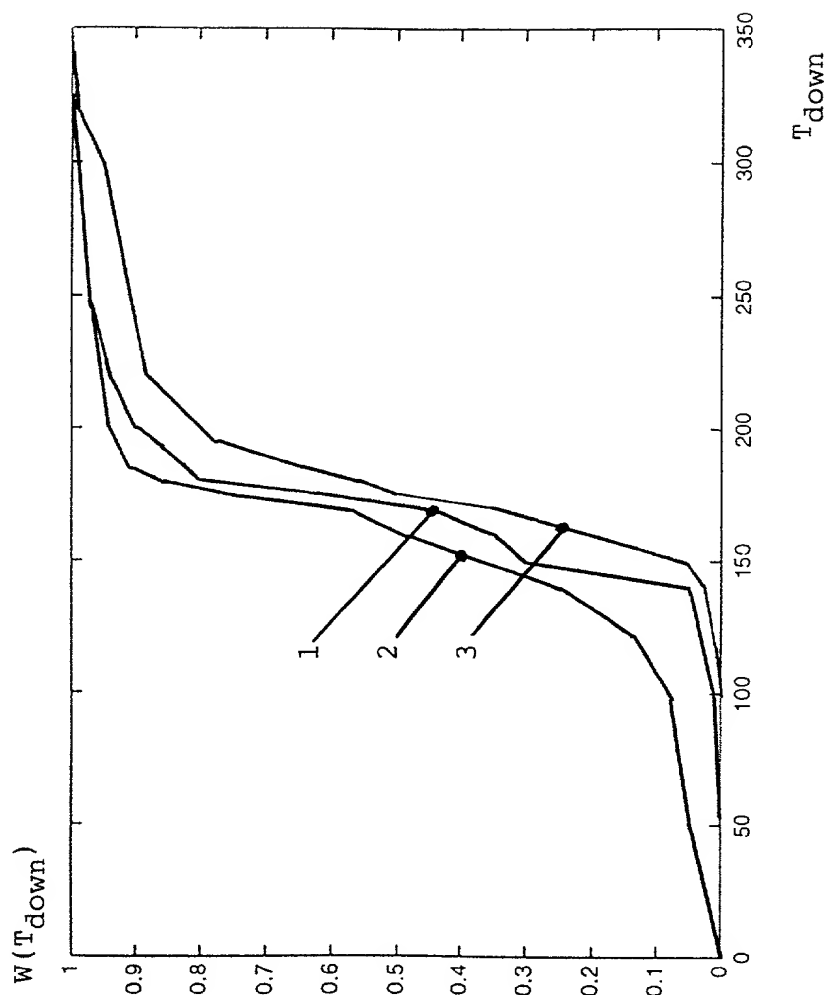


Fig. 1

Fig. 2

**COMBINED DECLARATION AND POWER OF ATTORNEY  
FOR UTILITY PATENT APPLICATION**

Attorney's Docket No.

004501-349

As a below-named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name;

I BELIEVE I AM THE ORIGINAL, FIRST AND SOLE INVENTOR (if only one name is listed below) OR AN ORIGINAL, FIRST AND JOINT INVENTOR (if more than one name is listed below) OF THE SUBJECT MATTER WHICH IS CLAIMED AND FOR WHICH A PATENT IS SOUGHT ON THE INVENTION ENTITLED:

METHOD FOR ASSESSING THE RELIABILITY OF TECHNICAL SYSTEMS

the specification of which

(check one)



is attached hereto;



was filed on March 7, 2000 as

Application No. \_\_\_\_\_

and was amended on \_\_\_\_\_;  
(if applicable)

I HAVE REVIEWED AND UNDERSTAND THE CONTENTS OF THE ABOVE-IDENTIFIED SPECIFICATION, INCLUDING THE CLAIMS, AS AMENDED BY ANY AMENDMENT REFERRED TO ABOVE;

I ACKNOWLEDGE THE DUTY TO DISCLOSE TO THE OFFICE ALL INFORMATION KNOWN TO ME TO BE MATERIAL TO PATENTABILITY AS DEFINED IN TITLE 37, CODE OF FEDERAL REGULATIONS, Sec. 1.56 (as amended effective March 16, 1992);

I do not know and do not believe the said invention was ever known or used in the United States of America before my or our invention thereof, or patented or described in any printed publication in any country before my or our invention thereof or more than one year prior to said application; that said invention was not in public use or on sale in the United States of America more than one year prior to said application; that said invention has not been patented or made the subject of an inventor's certificate issued before the date of said application in any country foreign to the United States of America on any application filed by me or my legal representatives or assigns more than twelve months prior to said application;

I hereby claim foreign priority benefits under Title 35, United States Code Sec. 119 and/or Sec. 365 of any foreign application(s) for patent or inventor's certificate as indicated below and have also identified below any foreign application for patent or inventor's certificate on this invention having a filing date before that of the application(s) on which priority is claimed:

**COMBINED DECLARATION AND POWER OF ATTORNEY**

Attorney's Docket No.

004501-349

COUNTRY/INTERNATIONAL	APPLICATION NUMBER	DATE OF FILING (day, month, year)	PRIORITY CLAIMED
Germany	199 10 098.5	08.03.99	YES <input checked="" type="checkbox"/> NO <input type="checkbox"/>
			YES <input type="checkbox"/> NO <input type="checkbox"/>

I hereby appoint the following attorneys and agent(s) to prosecute said application and to transact all business in the Patent and Trademark Office connected therewith and to file, prosecute and to transact all business in connection with international applications directed to said invention:

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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